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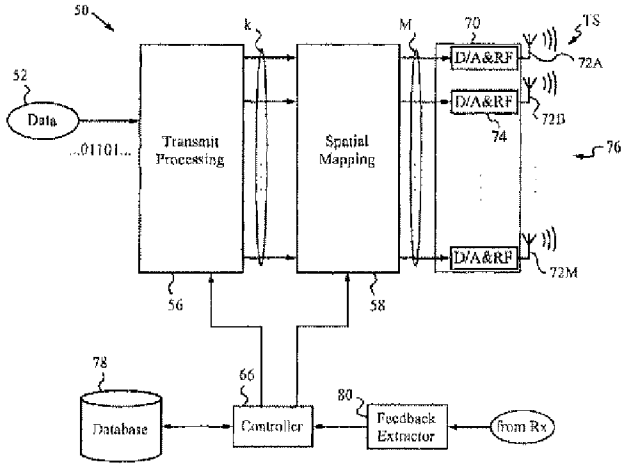
(54) Title: MODE SELECTION FOR DATA TRANSMISSION IN WIRELESS COMMUNICATION CHANNELS BASED ON STATISTICAL PARAMETERS



(57) Abstract: A method and communication system for selecting a mode for encoding data for transmission in a wireless communication channel between a transmit unit and a receive unit. The data is initially transmitted in an initial mode and the selection of the subsequent mode is based on a selection of first-order and second-order statistical parameters of short-term and long-term quality parameters. Suitable short-term quality parameters include signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR), power level and suitable long-term quality parameters include error rates such as bit error rate (BER) and packet error rate (PER). The method of the invention can be employed in Multiple Input Multiple Output (MIMO), Multiple Input Single Output (MISO), Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) communication systems to make subsequent mode selection faster and more efficient. Furthermore the method can be used in communication systems employing various transmission protocols including OFDMA, FDMA, CDMA, TDMA.

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Mode Selection for Data Transmission in Wireless Communication Channels Based on Statistical Parameters

FIELD OF THE INVENTION

The present invention relates generally to wireless communication systems and methods, and more particularly to mode selection for encoding data for transmission in a wireless communication channel based on statistical parameters.

BACKGROUND OF THE INVENTION

Wireless communication systems serving stationary and mobile wireless subscribers are rapidly gaining popularity. Numerous system layouts and communications protocols have been developed to provide coverage in such wireless communication systems.

Wireless communications channels between transmit and receive devices are inherently variable and their quality fluctuates. Specifically, the quality parameters of such communications channels vary in time. Under good conditions wireless channels exhibit good communication parameters, e.g., large data capacity, high signal quality, high spectral efficiency and throughput. At these times significant amounts of data can be transmitted via the channel reliably. However, as the channel changes in time, the communication parameters also change. Under altered conditions former data rates, coding techniques and data formats may no longer be feasible. For example, when channel performance is degraded the transmitted data may experience excessive corruption yielding unacceptable communication parameters. For instance, transmitted data can exhibit excessive bit-error rates or packet error rates. The degradation of the channel can be due to a multitude of factors such as general noise in the channel, multi-path fading, loss

of line-of-sight path, excessive Co-Channel Interference (CCI) and other factors.

In mobile systems, signal degradation and corruption is chiefly due to interference from other cellular users within or near a given cell and multipath fading, in which the received amplitude and phase of a signal varies over time. The fading rate can reach as much as 200 Hz for a mobile user traveling at 60 mph at PCS frequencies of about 1.9 GHz. In such environments, the problem is to cleanly extract the signal of the user being tracked from the collection of received noise, CCI, and desired signal portions.

In Fixed Wireless Access (FWA) systems, e.g., where the receiver remains stationary, signal fading rate is less than in mobile systems. In this case, the channel coherence time or the time during which the channel estimate remains stable is longer since the receiver does not move.

Prior art wireless systems have employed adaptive modulation of the transmitted signals with the use of feedback from the receiver as well as adaptive coding and receiver feedback to adapt data transmission to changing channel conditions. Such adaptive modulation is applied to Single Input Single Output (SISO) and Multiple Input Multiple Output (MIMO) systems, e.g., systems with antenna arrays at the transmit and receive ends.

In both SISO and MIMO systems, however, the fundamental problem of efficient choice of the mode to be applied to the transmitted data remains. For general prior art on the subject the reader is referred to A.J. Goldsmith et al., "Variable-rate variable power MQAM for fading channels", IEEE Transactions of Communications, Vol. 45, No. 10, Oct. 1997, pp. 1218-1230; P.

Schramm et al., "Radio Interface of EDGE, a proposal for enhanced data rates in existing digital cellular systems", Proceedings IEEE 48th Vehicular Technology Conference (VTC' 1998), pp. 1064-1068; and Van Noblen et al., "An adaptive link protocol with enhanced data rates for GSM evolution", IEEE Personal Communications, February 1999, pp. 54-63.

U.S. Pat. No. 6,044,485 to Dent et al. teaches a transmission method and system which adapts the coding of data based on channel characteristics. The channel characteristics are obtained either from a channel estimation circuit or from an error feedback signal. In particular, when the signal-to-noise (SNR) characteristic is chosen as an indicator of the state of the channel, then a different coding is applied to the data being transmitted for high and low SNR states of the channel. In addition, the encoding also employs information derived from the cyclic redundancy check (CRC).

The method taught by Dent varies the coding rate only and not the modulation rate. This method does not permit one to select rapidly and efficiently from a large number of encoding modes to adapt to varying channel conditions.

U.S. Pat. No. 5,559,810 to Gilbert et al. teaches a communication system using data reception history for selecting a modulation technique from among a plurality of modulation techniques to thus optimize the use of communication resources. At least one block of data is transmitted with a particular modulation technique and a data reception history is maintained to indicate transmission errors, e.g., by keeping a value of how many blocks had errors. The data reception history is updated and used to determine an estimate of transmission

signal quality for each modulation technique. This value is then used in selecting the particular modulation technique.

The system and method taught by Gilbert rely on tracking errors in the reception of entire blocks of data. In fact, signal quality statistics, e.g., signal-to-interference and noise ratio (SINR) are derived from the error numbers for entire blocks of data, which requires a significant amount of time. Thus, this method does not permit one to select rapidly and efficiently from a large number of encoding modes to adapt to varying channel conditions, especially in the event of rapid fades as encountered in mobile wireless systems.

It would be an advance to provide a mode selection technique which allows the system to rapidly and efficiently select the appropriate mode for encoding data in a quickly changing channel. It is important that such technique be efficient in all wireless systems, including Multiple Input Multiple Output (MIMO), Multiple Input Single Output (MISO), Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) systems as well as systems using multiple carrier frequencies, e.g., OFDM systems.

SUMMARY

The present invention provides a method for selecting a mode for encoding data for transmission in a wireless communication channel between a transmit unit and a receive unit. The data is first encoded in accordance with an initial mode and transmitted from the transmit unit to the receive unit. One or more quality parameters are sampled in the data received by the receive unit. Then, a first-order statistical parameter and a second-order statistical parameter of the quality parameter are

computed and used for selecting a subsequent mode for encoding the data.

The one or more quality parameters can include a short-term quality parameter or several short-term quality parameters and be selected among parameters such as signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR) and power level. Conveniently, a first sampling time or window is set during which the short-term quality parameter is sampled. In one embodiment, the length of the first sampling window is based on a coherence time of the wireless communication channel. In another embodiment, the duration of the first sampling window is based on a delay time required to apply the subsequent mode to encode the data at the transmit unit. In yet another embodiment, the second-order statistical parameter is a variance of the short-term quality parameter and the length of the first sampling window is selected on the order of the variance computation time.

The one or more quality parameters can also include a long-term quality parameter or several long-term quality parameters. The long-term quality parameter can be an error rate of the data, such as a bit error rate (BER) or a packet error rate (PER) at the receive unit. Again, it is convenient to set a second sampling time or window during which the long-term quality parameter is sampled. In one embodiment, the first-order statistical parameter is a mean of the long-term quality parameter and the length of the second sampling window is set on the order of the mean computation time. In another embodiment, the length of the second sampling window is set on the order of an error rate computation time.

In many instances, it is convenient when the first-order statistical parameter is a mean of the quality parameter and the second-order statistical parameter is a variance of the quality parameter. The variance can include two variance types: a temporal variance and a frequency variance. The latter is useful in systems employing multiple frequencies for transmitting the data. Specifically, it is particularly convenient to compute both temporal and frequency variances when the data is transmitted in accordance with a multi-carrier scheme.

The initial mode for encoding the data can be selected from a set of modes. The set of modes can be made up of a number of modes which are likely to work based on a preliminary analysis of the channel. The set of modes can be organized in accordance with the at least one quality parameter whose first-order and second-order statistics are used in subsequent mode selection.

Conveniently, the subsequent mode is communicated to the transmit unit and applied to the data to maximize a communication parameter in the channel. For example, the subsequent mode can maximize data capacity, signal quality, spectral efficiency or throughput of the channel or any other communication parameter or parameters as desired.

The method of the invention can be used in Multiple Input Multiple Output (MIMO), Multiple Input Single Output (MISO), Single Input Single Output (SISO) and Single Input Multiple Output (SIMO) communication systems, e.g., receive and transmit units equipped with multiple antennas. Furthermore the method can be used in communication systems employing various transmission protocols including OFDMA, FDMA, CDMA, TDMA.

The method of invention can also be used for selecting the mode from a set of modes and adjusting the selection. For this purpose data encoded in an initial mode selected from the set of modes is received by the receive unit. The short-term quality parameter is then sampled to determine a statistical parameter of the short-term quality parameter. Of course, the statistical parameter can include any combination of first-order and second-order statistical parameters. The subsequent mode is selected based on the short-term statistical parameter. In addition, the long-term quality parameter of the data received by the receive unit is also sampled. The subsequent mode selected based on the short-term statistical parameter is then adjusted based on the long-term quality parameter.

The set of modes can be arranged in any suitable manner, e.g., it can be arranged in a lookup table and ordered by the short-term quality parameter and specifically the first-order and/or second-order statistics of the short-term quality parameter for easy selection. In fact, the lookup table can be modified based on the short-term quality parameter.

The invention also encompasses a system for assigning a subsequent mode for encoding data. The system has a transmit unit equipped with a transmit processing block for encoding the data in a mode. A receive unit is provided for receiving the data transmitted from the transmit unit. The receive unit has a statistics computation block for sampling at least one quality parameter of the received data and computing the first-order and second-order statistical parameters of the data. The receive unit also has a mode selection block for assigning the subsequent mode based on the first-order and second-order statistical parameters.

Conveniently, the system has at least one database containing the set of modes from which the mode, e.g., the initial mode, and the subsequent mode are selected. In one case, the receive has a first database containing the modes and the transmit unit has a second such database.

The system also has a feedback mechanism for communicating the subsequent mode from the receive unit to the transmit unit. This feedback mechanism can be a separate mechanism or comprise the time-division duplexing (TDD) mechanism.

A detailed description of the invention and the preferred and alternative embodiments is presented below in reference to the attached drawing figures.

BRIEF DESCRIPTION OF THE FIGURES

Fig. 1 is a simplified diagram illustrating a communication system in which the method of the invention is applied.

Fig. 2 is a graph illustrating the effects of channel variation in time and frequency.

Fig. 3 is a block diagram of an exemplary transmit unit in accordance with the invention.

Fig. 4 is a block diagram of an exemplary receive unit in accordance with the invention.

Fig. 5 is a schematic diagram illustrating data transmitted in a wireless communication channel.

DETAILED DESCRIPTION

The method and systems of the invention will be best understood after first considering the simplified diagram of Fig. 1

illustrating a portion of a wireless communication system **10**, e.g., a cellular wireless system in which the method of invention can be employed. For explanation purposes, downlink communication will be considered where a transmit unit **12** is a Base Transceiver Station (BTS) and a receive unit **14** is a mobile or stationary wireless user device. Of course, the method can be used in uplink communication from receive unit **14** to BTS **12**.

Exemplary user devices **14** include mobile receive units such as a portable telephone **14A**, a car phone **14B** and a stationary receive unit **14C**. Receive unit **14C** can be a wireless modem used at a residence or any other fixed wireless unit. Receive units **14A** and **14C** are equipped with multiple antennas or antenna arrays **20**. These receive units can be used in Multiple Input Multiple Output (MIMO) communications taking advantage of techniques such as spatial multiplexing or antenna diversity. Receive unit **14B** has a single antenna **19** and can be used in Single Input Single Output (SISO) communications. It will be understood by those skilled in the art that receive units **14A**, **14B**, **14C**, could be equipped in SISO, MISO (Multiple Input Single Output), SIMO (Single Input Multiple Output), or MIMO configurations. For example, in Fig. 1 receive unit **14B** is shown having a single antenna therefore it can be employed in SISO or MISO configurations. MISO configuration can be realized in the case of **14B** for example by receiving signals from the antenna array at BTS **12A** or from distinct BTS such as **12B**, or any combination thereof. With the addition of multiple receive antennas **14B**, as **14A** and **14C**, could also be used in SIMO or MIMO configurations. In any of the configurations discussed above, the communications techniques can employ single-carrier or multi-carrier communications techniques.

A first exemplary transmit unit **12** is a BTS **12A** equipped with an antenna array **16** consisting of a number of transmit antennas **18A, 18B, ..., 18M** for MIMO communications. Another exemplary transmit unit **12** is a BTS **12B** equipped with a single omnidirectional antenna **13**. BTSs **12A, 12B** send data in the form of transmit signals TS to receive units **14A, 14B, 14C** via wireless communications channels **22**. For simplicity, only channel **22A** between BTS **12A** and receive unit **14A** and channel **22B** between BTS **12B** and receive unit **14C** are indicated.

The time variation of channels **22A, 22B** causes transmitted signal TS to experience fluctuating levels of attenuation, interference, multi-path fading and other deleterious effects. Therefore, communication parameters of channel **22A** such as data capacity, signal quality, spectral efficiency and throughput undergo temporal changes. The cumulative effects of these variations of channel **22A** between BTS **12A** and receive unit **14A** are shown for illustrative purposes in Fig. 2. In particular, this graph shows the variation of a particular quality parameter, in this case signal strength of receive signal RS at receive unit **14A** in dB as a function of transmission time t and frequency f of transmit signal TS sent from transmit unit **12A**. Similar graphs can be obtained for other quality parameters, such as signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR) as well as any other quality parameters known in the art. Of the various quality parameters signal strength (power level), SINR and SNR are generally convenient to use because they can be easily and rapidly derived from receive signals RS as is known in the art.

In accordance with the invention, a mode for encoding data at transmit units **14** is selected based on a first order statistical parameter and a second order statistical parameter

of the quality parameter. The details of the method will now be explained by referring to the operation of a transmit unit **50**, as illustrated in Fig. 3 and a receive unit **90** as illustrated in Fig. 4.

Transmit unit **50** receives data **52** to be transmitted; in this case a stream of binary data. Data **52** is delivered to a transmit processing block **56**. Transmit processing block **56** subdivides data **52** into a number k of parallel streams. Then, processing block **56** applies an encoding mode to each of the k streams to thus encode data **52**. It should be noted, that before transmission data **52** may be interleaved and pre-coded by an interleaver and a pre-coder (not shown). The purpose of interleaving and pre-coding is to render the data more robust against errors. Both of these techniques are well-known in the art.

The mode is determined by a modulation during which data **52** is mapped into a constellation at a given modulation rate, and a coding rate at which this translation is performed. For example, data **52** can be converted into symbols through modulation in a constellation selected from among PSK, QAM, GMSK, FSK, PAM, PPM, CAP, CPM or other suitable constellations. The transmission rate or throughput of data **52** will vary depending on the modulation and coding rates used in each of the k data streams.

Table 1

Mode	Modulation Rate (bits/symbol)	Coding Rate	Throughput (bits/s/Hz)
1	2	3/4	3/2
2	2	2/3	4/3
3	2	1/2	1
4	2	1/3	2/3

5	4	3/4	3
6	4	2/3	8/3
7	4	1/2	2
8	4	1/3	4/3
9	5	3/4	15/4
10	5	2/3	10/3
11	5	1/2	5/2
12	5	1/3	5/3
13	6	3/4	9/2
14	6	2/3	4
15	6	1/2	3
16	6	1/3	2

Table 1 illustrates some typical modes with their modulation rates and coding rates and the corresponding throughputs for data **52**. The modes are indexed by a mode number so as to conveniently identify the modulation and coding rates which are to be applied to data **52** in each mode. Lookup tables analogous to Table 1 for other coding and modulation rates can be easily derived as these techniques are well-known in the art.

Referring back to Fig. 3, a set of modes, arranged conveniently in the form of lookup table indexed as described above, is stored in a database **78** of transmit unit **50**. Database **78** is connected to a controller **66**, which is also connected to transmit processing block **56** and spatial mapping unit **58**. Controller **66** controls which mode from database **78** is applied to each of the k streams and spatial mapping to be performed by spatial mapping unit **58**.

In addition to encoding the k streams, transmit processing block **56** adds training information into training tones **T** (see Fig. 5) and any other control information, as is known in the art. Thus processed, the k streams are sent to an up-conversion and RF amplification stage **70** having individual digital-to-analog converters and up-conversion/RF amplification

blocks **74** through the spatial mapping unit **58**. The spatial mapping unit **58** maps the k streams to M inputs of the up-conversion and RF amplification stage **70**. The M outputs of amplification stage **70** lead to corresponding M transmit antennas **72** of an antenna array **76**.

A person skilled in the art will recognize that the number M of transmit antennas **72** does not have to be equal to the number of streams k. That is because various spatial mappings can be employed in assigning streams k to transmit antennas **72**. In one mapping, a certain transmit antenna **72B** transmits one of the k streams. In another mapping, a number of transmit antennas **72** transmit the same stream k. In yet another embodiment, the k streams are assigned to M antennas **72** or a subset thereof via the spatial mapping unit **58** and the unit **70**. In fact, any kind of mapping involving the use of spatial multiplexing (SM) and antenna diversity can be used in the method and system of the invention.

Transmit antennas **72** transmit data **52** in the form of transmit signals TS. Fig. 5 illustrates, as will be recognized by those skilled in the art, a multicarrier transmission scheme with n frequency carriers (tones). The vertical axis illustrates frequency carriers while the horizontal axis illustrates OFDM symbol periods. Each block corresponds to one of n frequency carriers during an OFDM symbol. The blocks marked with D correspond to data and the blocks marked with T correspond to training.

Fig. 5 indicates that training is performed on all tones during an OFDM training symbol, it will be clear to a person skilled in the art that a subset of these tones could be used for

training and the corresponding frequency response could be computed at the receiver by interpolating.

Transmit signals TS propagate through channel **22** and there experience the effects of changing conditions of channel **22**, as described above. Transmit signals TS are received in the form of receive signals RS by a receive antenna **91A** belonging to an antenna array **92** of a receive unit **90**, shown in Fig. 4.

Again referring to Fig. 4, receive unit **90** has N receive antennas **91A**, **91B**, ..., **91N** for receiving receive signals RS from transmit unit **50**. Receive unit **90** can be any suitable receiver capable of receiving receive signals RS via the N receive antennas **92**. Exemplary receivers include linear equalizer receivers, decision feedback equalizer receivers, successive cancellation receivers, and maximum likelihood receivers.

Receive unit **90** has an RF amplification and down-conversion stage **94** having individual RF amplification/down-conversion/ and analog-to-digital converter blocks **96** associated with each of the N receive antennas **91A**, **91B**, ..., **91N**. The N outputs of stage **94** are connected to a receive processing block **98** which performs receive processing to recover the k streams encoded by transmit processing block **56** of transmit unit **50**. The recovered k streams are passed on to a signal detection, decoding and demultiplexing block **100** for recovering data **52**. In the case of antenna diversity processing it should be understood that k is equal to one thus there is only a single stream recovered.

The receive processing block **98** computes the quality parameters for each of k streams and sends this information to a

statistics computation block for computing statistical parameters of the one or more quality parameters. The method of the invention can recognize slow and rapid channel variations and allows for efficient mode selection by taking both types of variations into account. This is accomplished by taking into account at least two statistics of one or more quality parameters. This may include either or both short-term and long-term quality parameters. Suitable short-term quality parameters include signal-to-interference and noise ratio (SINR), signal-to-noise ratio (SNR) and power level. Suitable long-term quality parameters include error rates such as bit error rate (BER) and packet error rate (PER).

For example, in one embodiment, the first-order and second-order statistics are derived from a short-term quality parameter such as the SINR. In another embodiment statistics of both a short-term and a long-term quality parameter are used.

In the present embodiment the short-term quality parameter used is SINR. Statistics computation block **102** computes a first-order statistical parameter **104** and a second-order statistical parameter **106** of SINR. Conveniently, first-order statistical parameter **104** is mean SINR and second-order statistical parameter is a variance SINR. Variance **106** of SINR actually consists of two values, SINR temporal variance **106A** and SINR frequency variance **106B**. In systems which do not employ multi-carrier transmission schemes frequency variance **106B** does not have to be computed. It should be noted that each data stream of k streams will have an associated statistical parameter **104,106A, 106B**.

A window adjustment **108** such as a timing circuit is connected to statistics computation block **102**. Window adjustment **108**

sets a first time interval or first sampling window τ_1 (see Fig. 5) during which the SINR is sampled. Conveniently, SINR is sampled during training tones T occurring during sampling window τ_1. The present embodiment uses multiple carrier frequencies f_c and thus the SINR is sampled and computed by block **102** for data **52** transmitted at each of the n carrier frequencies f_c. By buffering the SINR values for all the training tones T during time window τ_1 statistics computation block **102** constructs the following matrix:

$$\begin{bmatrix} SINR_{1,1} & SINR_{1,2} & \cdots & SINR_{1,w} \\ SINR_{2,1} & \cdots & & \\ \cdots & & & \\ SINR_{n,1} & & & SINR_{n,w} \end{bmatrix}$$

where $SINR_{i,j}$ is the SINR at the i-th carrier frequency f_{ci} during training phase j. There are thus 1 to n carrier frequencies f_c and 1 to w training phases.

First-order statistical parameter **104** of short-term quality parameter, in this case mean SINR, can be expressed as:

$$SINR_{mean} = \frac{1}{n \cdot w} \sum_{i=1}^{n} \sum_{j=1}^{w} SINR_{i,j} .$$

Second-order statistical parameters **106A**, **106B** of short-term quality parameter, in this case SINR frequency variance and SINR time variance can be expressed as:

$$SINR_{var(freq)} = \frac{1}{n \cdot w} \sum_{i=1}^{w} \sum_{j=1}^{n} \left[SINR_{j,i} - \frac{1}{n} \sum_{k=1}^{n} SINR_{k,i} \right]^2 , \text{ and}$$

$$SINR_{var(time)} = \frac{1}{W}\sum_{k=1}^{W}\left[\frac{1}{n}\sum_{i=1}^{n} SINR_{i,k} - \left(SINR_{mean}\right)\right]^2$$

In general, the duration of first sampling window τ_1 takes into account general parameters of the communication system and/or channel **22**. For example, channel **22** has a coherence time during which the condition of channel **22** is stable. Of course, the coherence time will vary depending on the motion of receive unit **90**, as is known in the art. In one embodiment, window adjustment **108** sets first sampling window τ_1 based on the coherence time. Specifically, first sampling window τ_1 can be set on the order of or shorter than the coherence time. Thus, the first- and second-order statistical parameters **104**, **106A**, **106B** computed during time window τ_1 are minimally affected by loss of coherence. In another embodiment window adjustment **108** sets first sampling window τ_1 to be much larger than the coherence time.

Alternatively, window adjustment **108** sets first sampling window τ_1 on the order of or equal to a link update time or a delay time. This is the amount of time required for receive unit **90** to communicate to transmit unit **50** the SINR statistics and/or the appropriate mode selection based on these SINR statistics as explained below. The delay time is a design parameter limited by the complexity of computations involved and feedback from receive unit **90** to transmit unit **50**. Of course, the delay time of the system should preferably be less or significantly less than the channel coherence time when the window size τ_1 is chosen smaller than the coherence time. On the converse, when the delay time of the system is greater than channel coherence

time the window size τ_1 should also be chosen appropriately to be larger than the channel coherence time.

It should be noted that the first-order and second-order statistics of the short-term quality parameter, in the present case mean and variance of SINR could be sampled and computed over different sampling windows.

In accordance with yet another alternative, SINR frequency variance **106A** and SINR time variance **106B** require a variance computation time. Variance computation time is chosen as the minimum amount of time required to obtain an accurate value of variances **106A, 106B.** Window adjustment **108** therefore sets first sampling window τ_1' on the order of or equal to the variance computation time, the embodiment illustrated in Fig. 5 shows τ_1 and τ_1' to be equal.

In addition to the above computations, receive unit **90** also computes a long-term quality parameter, in this embodiment an error rate of data **52.** For example, receive unit **90** computes a bit error rate (BER) or a packet error rate (PER) of data **52.** It typically takes a much longer period of time than the length of first sampling windows τ_1, τ_1' to compute these error rates. Conveniently, these error rates are thus computed during second sampling window τ_2 or over an error rate computation time (see Fig. 5). The computation of these error values and circuits necessary to perform these computations are well known in the art.

It should be noted that long-term quality parameters can be sampled over two second sampling window lengths as well. In the present embodiment only first-order statistical parameter, mean BER is computed during second time window τ_2.

In the present embodiment long-term quality parameter computed is the packet error rate (PER). As is well known in the art, the packet error rate can be computed by keeping track of the cyclic redundancy check (CRC) failures on the received packets. PER computation is a well-known technique and is performed in this embodiment by a PER statistics circuit **110**. The PER computation can be used to further improve mode selection.

The first and second-order statistical parameters of the short term quality parameter **104**, **106A**, **106B** are delivered from statistics computation block **102** to a mode selection block **112**. The first-order statistical parameter of the long-term quality parameter, in this embodiment the mean PER is also delivered to block **112**. When used, the PER statistics circuit **110** is also connected to mode selection block **112** and delivers the PER statistics to it.

Mode selection block is connected to a database **114**, conveniently containing the same set of modes as database **78** of transmit unit **50**. The set of modes in database **114** is related to first-order statistical parameter **104** and second-order statistical parameters **106A**, **106B** of short-term quality parameter.

Block **112** selects the subsequent mode number for encoding data **52**. Block **112** is connected to a feedback block **116** and a corresponding transmitter **118** for transmission of the feedback

to transmit unit **50**. Here the convenience of indexing modes becomes clear, since feedback of an index number to transmit unit **50** does not require much bandwidth. It should be noted, that in the present embodiment a mode selection is made for each of the k streams. In other words, a mode index indicating the mode to be used for each of the k streams is fed back to transmit unit **50**. In another embodiment it may be appropriate to send a mode difference indicating how to modify the current mode for subsequent transmission. For example if the current transmission is mode 1, the mode index of the subsequent mode is 3, the mode difference would be 2. In yet another embodiment, it may be suitable to send the channel characteristics back to the transmitter. In this case the computation of statistics of the quality parameter, the mode selection are performed at the transmitter.

Referring back to Fig. 3, transmit unit **50** receives feedback from receive unit **90** via a feedback extractor **80**. Feedback extractor **80** detects the mode index or any other designation of the selected modes for each of the k streams and forwards this information to controller **66**. Controller **66** looks up the mode by mode index in database **78** and thus determines the modulation, coding rate and any other parameters to be used for each of the k streams. In the event of using time-division duplexing (TDD), which is a technique known in the art, the quality parameters can be extracted during the reverse transmission from receive unit **90** or remote subscriber unit and no dedicated feedback is required.

In one embodiment, when the system of invention is placed into operation, transmit processing block **56** first assigns an initial mode, e.g., one of the modes available in the set of modes stored in database **78** to each of the k streams. The

choice of initial modes can be made on previously known data, simulations or empirical results. Transmit unit **50** then transmits data **52** in the form of transmit signals TS to receive unit **90**.

Receive unit **90** receives receive signals RS, reconstructs data **52** therefrom, and computes first-order and second-order statistical parameters **104**, **106A**, **106B** of short-term quality parameter. Mode selection block **112** then selects from database **114** the subsequent mode based on parameters **104**, **106A**, **106B**.

Table 2

SINR variance (frequency)	SINR variance (temporal)	Table
		A
		B
		C
		D

Table C

SINR mean	Mode No.
40 dB	
35 dB	
25 dB	
10 dB	

Lookup tables 2 and C illustrate a portion of database **114** arranged to conveniently determine the mode number of a subsequent mode to be used in encoding data **52** based on the frequency and temporal variances of SINR (second-order statistical parameters of short-term quality parameter) and

mean SINR (first-order statistical parameter of short-term quality parameter). Table 2 is referenced to additional tables A, B, C and D (only table C shown) based on frequency and temporal variances **106A**, **106B** of SINR. For example, the third entry in Table 2 corresponds to table C where modes are ordered by mean SINR (first-order statistical parameter of short-term quality parameter). Thus, a subsequent mode to be applied in encoding data **52** can be easily obtained from database **114** by block **112** based on its mode number.

In addition to considering the short-term quality parameters, block **112**, as an option, can obtain at least one long-term quality parameter and its statistics, i.e., first-order statistical parameter or mean PER in this embodiment. Block **112** then uses mean PER to find adjustment value δ that is added to the mean SINR value. In other words, the mean SINR value used to look up the corresponding mode is now mean SINR+δ. Thus, subsequent mode selection is altered or adjusted by taking into account the long-term quality parameter.

Once mode selection block **112** determines which modes should be used for each of the k streams, these subsequent modes are fed back to transmit unit **50** and applied to the k streams. This operation repeats itself, and each new selection of subsequent modes is fed back to transmit unit **50** to thus account for the changing conditions of channel **22**.

In fact, any combination of short-term and long-term quality parameters and their first- and second-order statistics can be used to thus appropriately select modes which should be used in transmitting data **52**. The quality parameters can further be related to link quality parameters or communication parameters

such as BER, PER, data capacity, signal quality, spectral efficiency or throughput and any other parameters to support requisite user services (e.g., voice communication). It should be noted, that BER and PER are both quality parameters and communication parameters. The subsequent mode selection can be made to optimize any of these communication parameters.

The use of at least two statistical parameters provides improved channel characterization leading to better selection of a subsequent mode than in prior art systems. Adapting the timing window to the mode update delay further improves mode selection. Furthermore, the use of long-term statistical parameters in mode selection further refines subsequent mode selection over longer time periods.

A person skilled in the art will recognize that the method and system of invention can be used in with any data transmission technique such as OFDMA, FDMA, CDMA, TDMA. It will also be clear to one skilled in the art that the above embodiments may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A method for selecting a mode for encoding data for transmission in a wireless communication channel between a transmit unit and a receive unit, said method comprising:
   a) transmitting said data encoded in an initial mode from said transmit unit to said receive unit;
   b) sampling at least one quality parameter of said data received by said receive unit;
   c) computing a first-order statistical parameter of said at least one quality parameter;
   d) computing a second-order statistical parameter of said at least one quality parameter; and
   e) selecting a subsequent mode for encoding said data based on said first-order statistical parameter and said second-order statistical parameter.

2. The method of claim 1, wherein said at least one quality parameter comprises a short-term quality parameter and said method further comprises setting a first sampling window during which said short-term quality parameter is sampled.

3. The method of claim 2, wherein said wireless communication channel has a coherence time and said first sampling window is set based on said coherence time.

4. The method of claim 2, wherein said subsequent mode is applied after a delay time, and said first sampling window is set based on said delay time.

5. The method of claim 2, wherein said second-order statistical parameter is a variance of said short-term quality parameter, said variance being computed over a variance computation time and said first sampling window being set on the order of said variance computation time.

6. The method of claim 2, wherein said short-term quality parameter is selected from the group consisting of signal-to-interference and noise ratio, signal-to-noise ratio and power level.

7. The method of claim 1, wherein said at least one quality parameter comprises a long-term quality parameter and said method further comprises setting a second sampling window during which said long-term quality parameter is sampled.

8. The method of claim 7, wherein said first-order statistical parameter is a mean of said long-term quality parameter, said mean being computed over a mean computation time and said second sampling window being set on the order of said mean computation time.

9. The method of claim 7, wherein said long-term quality parameter comprises an error rate of said data at said receive unit.

10. The method of claim 9, wherein said error rate is computed over an error rate

computation time, and said second sampling window is set on the order of said error rate computation time.

11. The method of claim 9, wherein said error rate is selected from the group consisting of bit error rate and packet error rate.

12. The method of claim 1, wherein said first-order statistical parameter is a mean of said at least one quality parameter.

13. The method of claim 1, wherein said second-order statistical parameter is a variance of said at least one quality parameter.

14. The method of claim 13, wherein said data is transmitted at more than one frequency and said variance is a frequency variance.

15. The method of claim 13, wherein said data is transmitted in a multi-carrier scheme and said variance is a frequency variance.

16. The method of claim 13, wherein said variance is a temporal variance.

17. The method of claim 1, wherein said initial mode is selected from a set of modes related to said at least one quality parameter.

18. The method of claim 1, wherein said subsequent mode is selected to maximize a communication parameter.

19. The method of claim 18, wherein said communication parameter is selected from the group consisting of bit error rate, packet error rate, data capacity, signal quality, spectral efficiency and throughput.

20. The method of claim 1, further comprising communicating said subsequent mode to said transmit unit.

21. The method of claim 1, wherein at least one of said transmit unit and said receive unit are multiple input and multiple output units.

22. The method of claim 1, wherein said transmitting step is performed in accordance with a transmission technique selected from the group consisting of OFDMA, FDMA, CDMA, TDMA.

23. A method for selecting a mode from a set of modes for encoding data for transmission in a wireless communication channel between a transmit unit and a receive unit, said method comprising:

a) transmitting said data encoded in an initial mode selected from said set of modes from said transmit unit to said receive unit;

b) sampling a short-term quality parameter of said data received by said receive unit;

c) computing a statistical parameter of said short-term quality parameter;

d) selecting a subsequent mode from said set of modes for encoding said data based on said short-term statistical parameter;

e) sampling a long-term quality parameter of said data received by said receive unit; and

f) adjusting said subsequent mode selection in step d) based on said long-term quality parameter.

24. The method of claim 23, wherein said long-term quality parameter is an error rate selected from the group consisting of bit error rate and packet error rate.

25. The method of claim 23, further comprising setting a first sampling window during which said short-term quality parameter is sampled and setting a second sampling window during which said long-term quality parameter is sampled.

26. The method of claim 25, wherein said long-term quality parameter is an error rate and is computed over an error rate computation time, and said second sampling window is set on the order of said error rate computation time.

27. The method of claim 25, wherein said short-term quality parameter is selected from the group consisting of signal-to-interference and noise ratio, signal-to-noise ratio and power level.

28. The method of claim 23, wherein said set of modes is arranged in a lookup table and ordered by said short-term quality parameter.

29. The method of claim 28, wherein said adjusting comprises modifying said lookup table based on said long-term quality parameter.

30. The method of claim 23, wherein said statistical parameter comprises at least one statistical parameter selected from the group consisting of first-order statistical parameters and second-order statistical parameters.

31. A system for assigning a subsequent mode for encoding data for transmission in a wireless communication channel, said system comprising:

a) a transmit unit having a transmit processing block for encoding said data in a mode;

b) a receive unit for receiving said data transmitted from said transmit unit, said receive unit having:

1) a statistics computation block for sampling at least one quality parameter of said data and computing a first-order statistical parameter of said at least one quality parameter and a second-order statistical parameter of said at least one quality parameter;

2) a mode selection block for assigning said subsequent mode based on said first-order statistical parameter and said second-order statistical parameter.

32. The system of claim 31, further comprising at least one database containing a set of modes from which said mode and said subsequent mode are selected.

33. The system of claim 32, wherein said at least one database comprises a first database in said transmit unit and a second database in said receive unit.

34. The system of claim 31, further comprising a feedback mechanism for communicating said subsequent mode between said receive unit and said transmit unit.

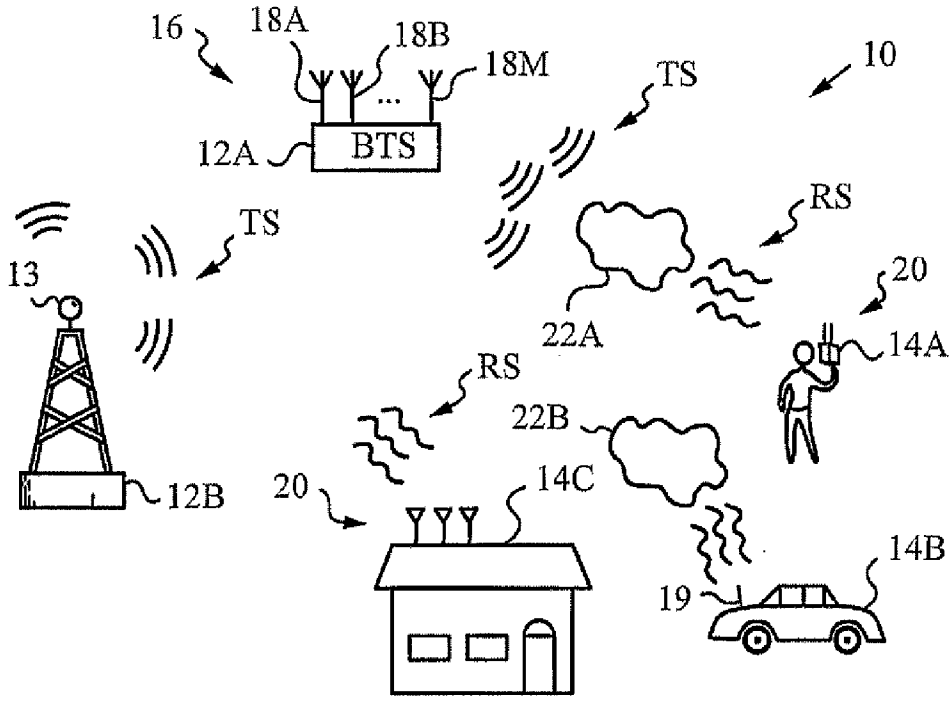
16
18A
18B
18M
10
TS
12A
BTS
TS
RS
13
20
22A
14A
RS
22B
20
14C
12B
14B
19

FIG. 1

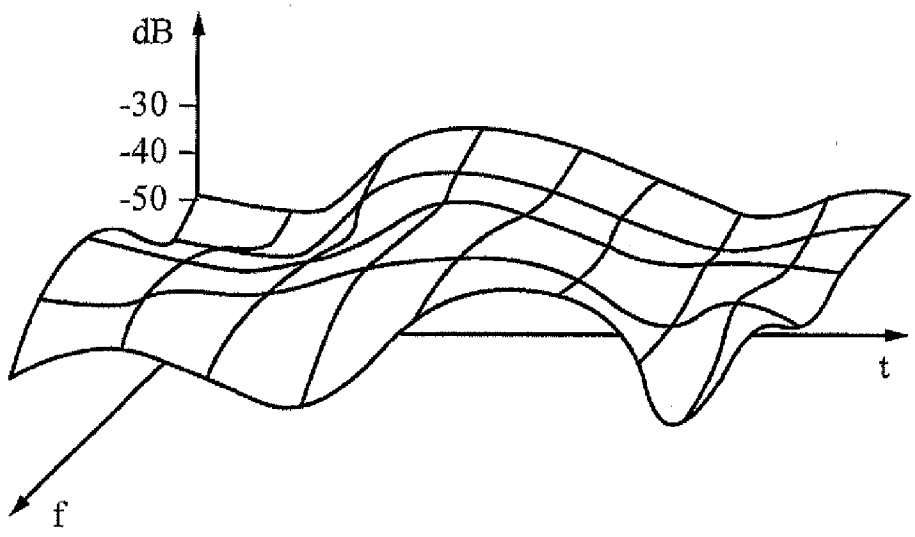
dB
-30
-40
-50
t
f

FIG. 2

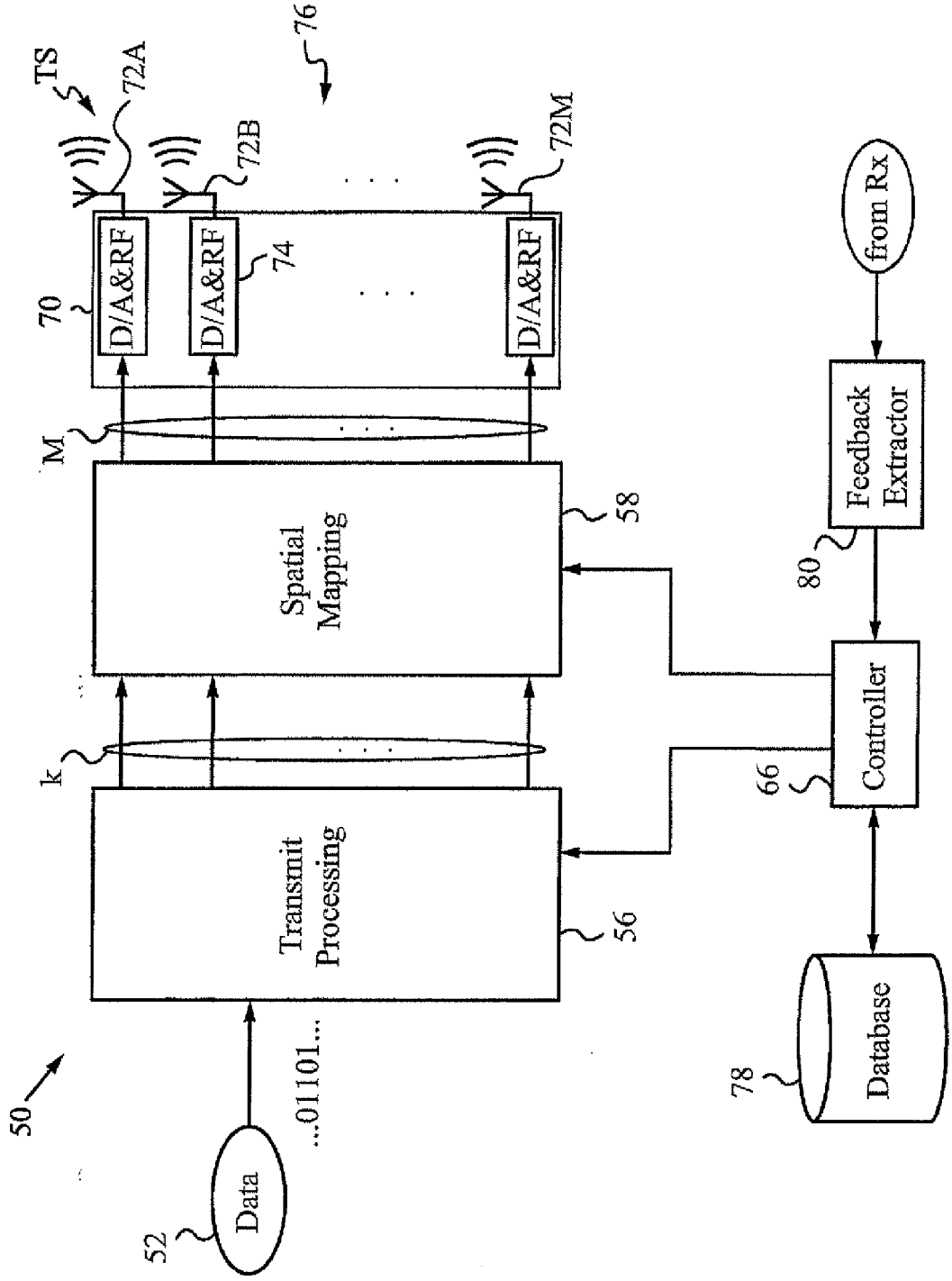
50
52
Data
...01101...
Transmit Processing
56
k
Spatial Mapping
58
M
70
D/A&RF
D/A&RF
D/A&RF
74
72A
72B
72M
TS
76
Feedback Extractor
80
from Rx
Controller
66
Database
78

FIG. 3

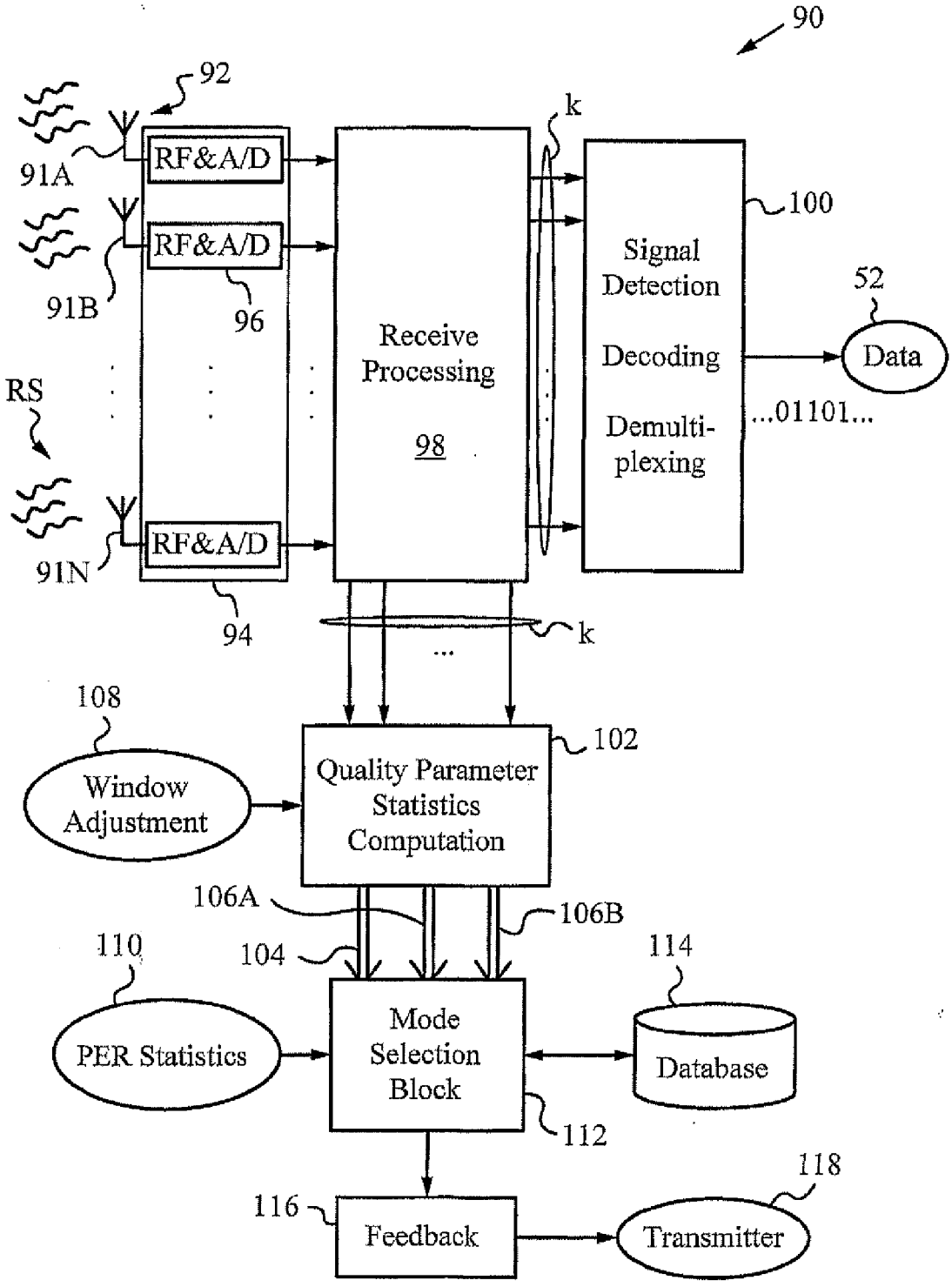
90
92
91A
91B
RS
91N
RF&A/D
RF&A/D
RF&A/D
96
94
k
Receive Processing
98
k
Signal Detection
Decoding
Demulti-plexing
100
52
Data
...01101...
108
Window Adjustment
102
Quality Parameter Statistics Computation
106A
106B
104
110
PER Statistics
Mode Selection Block
112
114
Database
116
Feedback
118
Transmitter

FIG. 4

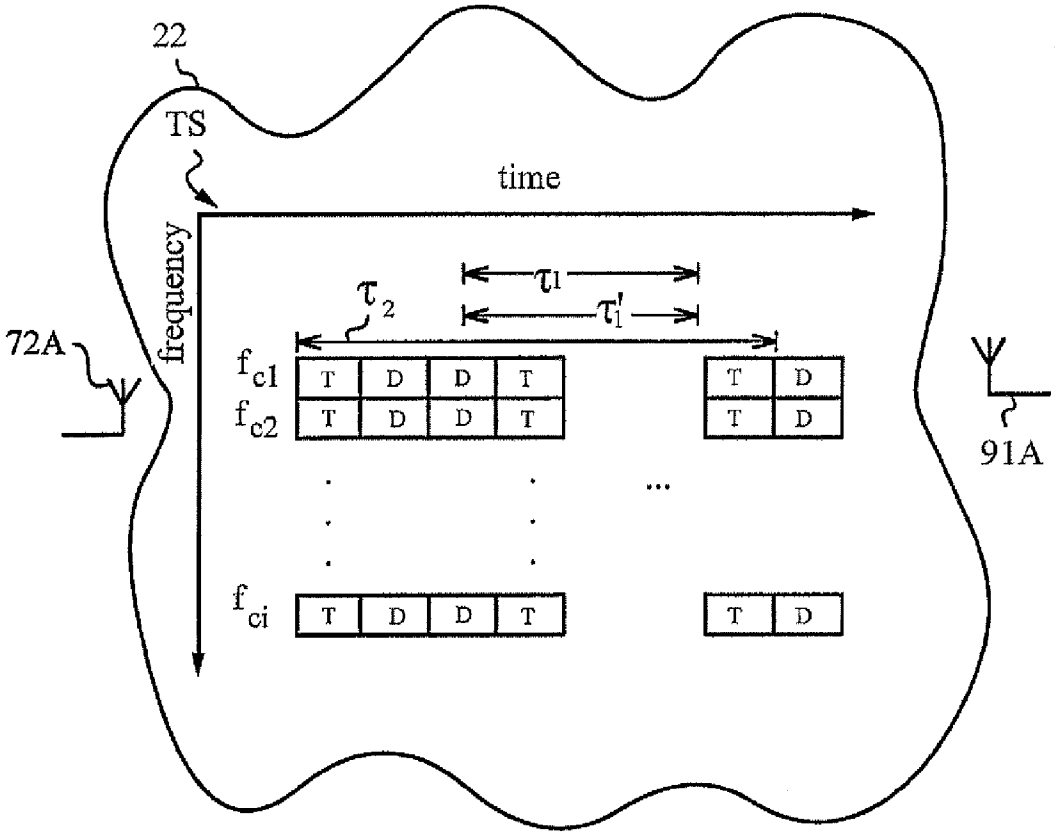
22
TS
time
frequency
72A
91A
τ_2
τ_1
τ_1'
f_{c1}
f_{c2}
f_{ci}
T D D T
T D
...

FIG. 5